

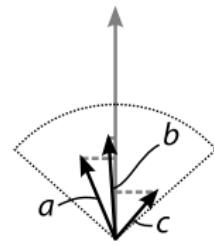
Direct jet reconstruction in $p + p$ and Cu + Cu collisions with the PHENIX detector

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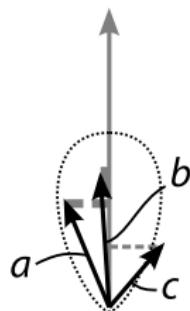
APS DNP Meeting 2009, Session BB

Gaussian filter



Cone

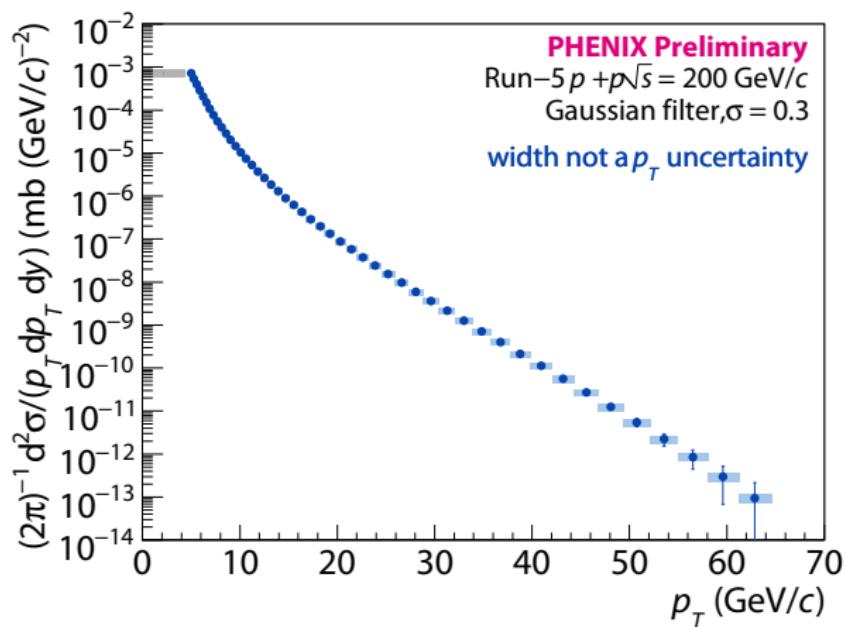
$$\iint_{\mathbb{R} \times S^1} d\eta' d\varphi' p_T(\eta', \varphi') \exp \left[-\frac{(\eta - \eta')^2 + (\varphi - \varphi')^2}{2\sigma^2} \right] = \max!$$



Filter

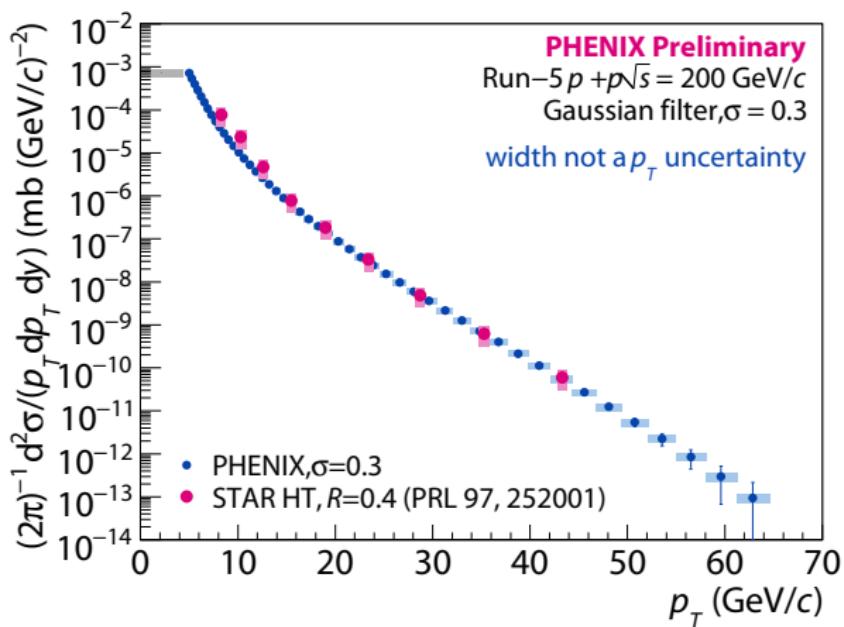
- Seedless
- Cone-like, but without infrared and collinear unsafety from hard angular cut-off
- Shape of the filter:
 - Optimizes the signal-to-background by focusing on the core of the jet
 - Stabilizes the jet axis in the presence of background
- Naturally handles isolated particles vs. collective background

Run-5 $p + p$ spectrum



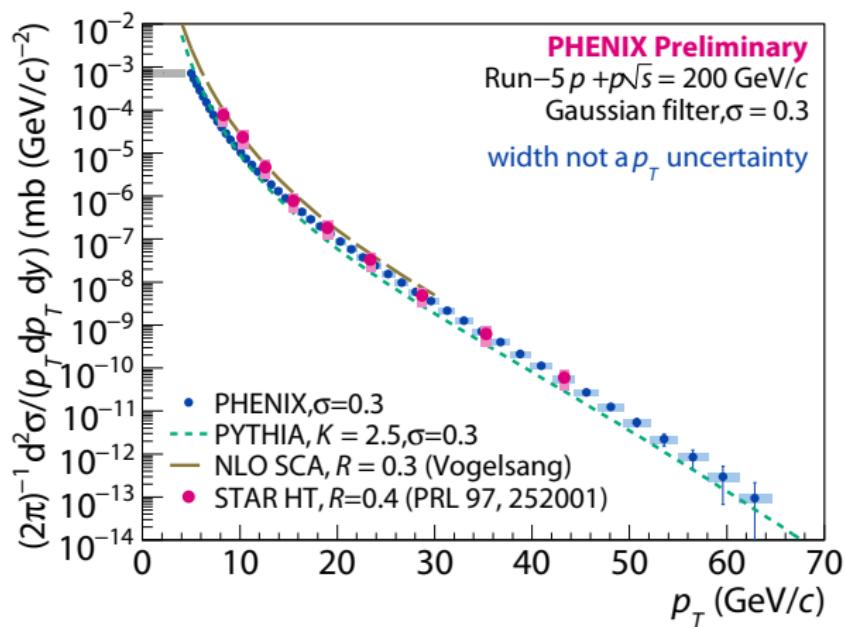
- $\int \mathcal{L} = 2.2 \text{ pb}^{-1}$
- Rate sufficient to measure 10 orders of magnitude

Run-5 $p + p$ spectrum



- Cross section consistent with STAR HT, but $\approx 20 \text{ GeV}/c$ further p_T reach
- $\sigma = 0.3$ not the same as $R = 0.4$ midpoint cone, but apparently close

Run-5 $p + p$ spectrum



- PYTHIA leading order K and NLO SCA also applies to oranges
- NLO calculation for larger p_T range and using filter is needed

Jet reconstruction in RHIC heavy ion: fake jets

- Large $dN/d\eta$, small jet σ_{pp} (vs. LHC):

⇒ Cu + Cu central jet yield at 10 GeV/c,

$$\frac{1}{2\pi} \frac{1}{N_{\text{evt}}} \frac{dN}{p_T dp_T dy} \approx 10^{-6} (\text{GeV}/c)^{-2} :$$

⇒ Several approach are proposed/may be suitable for jet reconstruction:

- 1 Reconstruct only very high p_T jets
- 2 Apply a large p_T cut on fragments
- 3 Statistically subtract the background
- 4 Direct rejection of fake jets

- Approaches (1), (2) limits you to RHIC kinematic edge or introduce large biases
- Approach (3) requires accurate knowledge about the background
- Approach (4) is preferred by PHENIX:
 - Low and controllable biases
 - Residual systematic errors easier to estimate/correct

Gaussian fake rejection

- Cut on the overall shape of the jet
- Inspired by the principle of Gaussian filter
- Strategy:

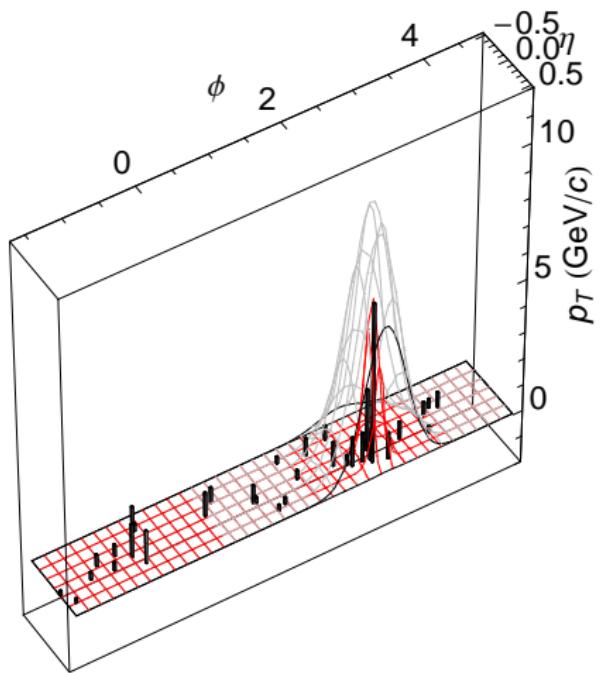
1 Sum p_T^2 inside a Gaussian kernel to obtain a discriminant:

$$g_{\sigma_{\text{dis}}}(\eta, \varphi) = \sum_{i \in \text{fragment}} p_{T,i}^2 \exp \left[-\frac{(\eta_i - \eta)^2 + (\varphi_i - \varphi)^2}{2\sigma_{\text{dis}}^2} \right],$$

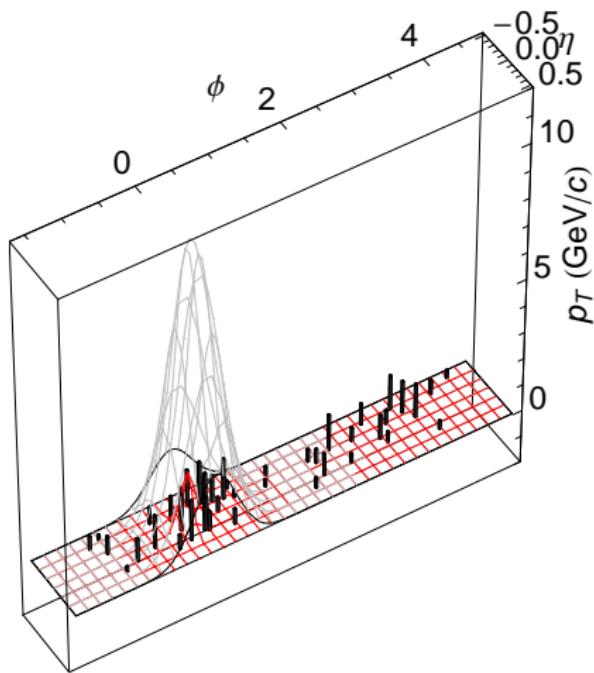
- 2 Gaussian kernel $\sigma_{\text{dis}} \approx 0.1$
3 (Technical detail: allow adaption for jets with very close maxima, obtain an updated $g'_{\sigma_{\text{dis}}}$)

- Cut on $g'_{0.1} = \text{weighted } p_T^2\text{-sum}$
- In central Au + Au HIJING simulation proves to be more effective than $\sigma/\sqrt{\langle A \rangle}$ (Cacciari & Salam, Phys. Lett. B **659**, 119, 2008) and Σj_T (Grau *et al.*, arXiv:0810.1219, 2008)

Principle of fake rejection



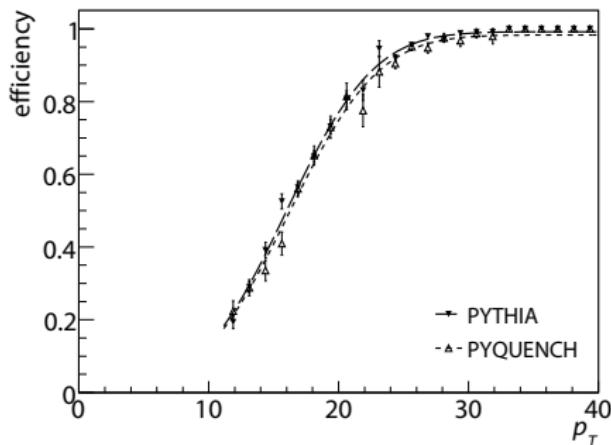
9.6 GeV/c jet passing fake rejection



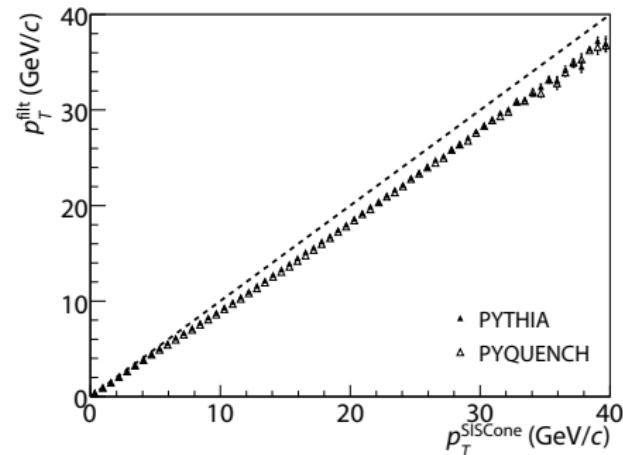
Rejected 10.8 GeV/c background fluctuation

Fake rejection in PYQUENCH

- Fake rejection at $g'_{0,1} > 54 \text{ (GeV/c)}^2$ for central Au + Au.



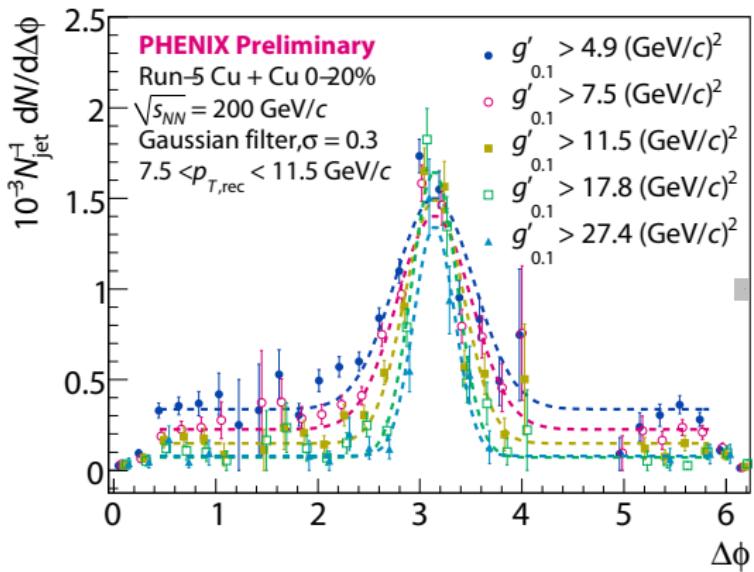
Efficiency turn-on after applying fake rejection



Energy scale $\sigma = 0.3$ Gaussian filter
against $R = 0.4$ SIScone

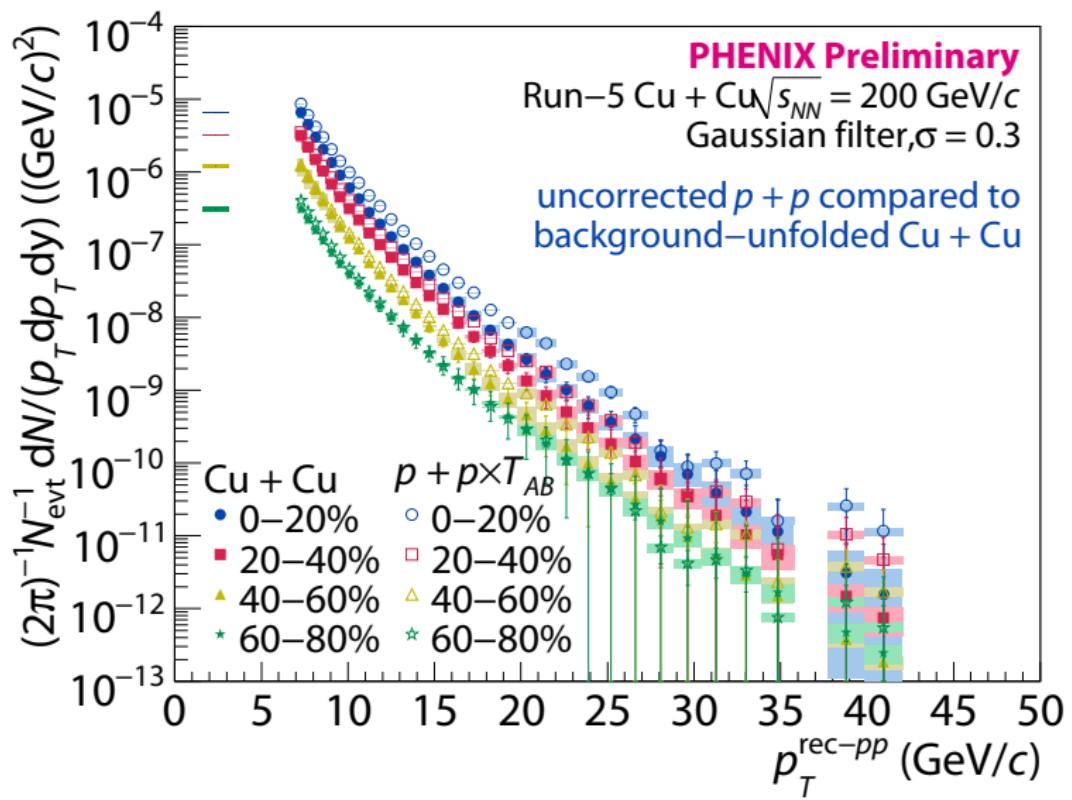
- Difference quenched vs. $p + p$ jets negligible (vs. our current systematics)

Fake rejection in Cu + Cu

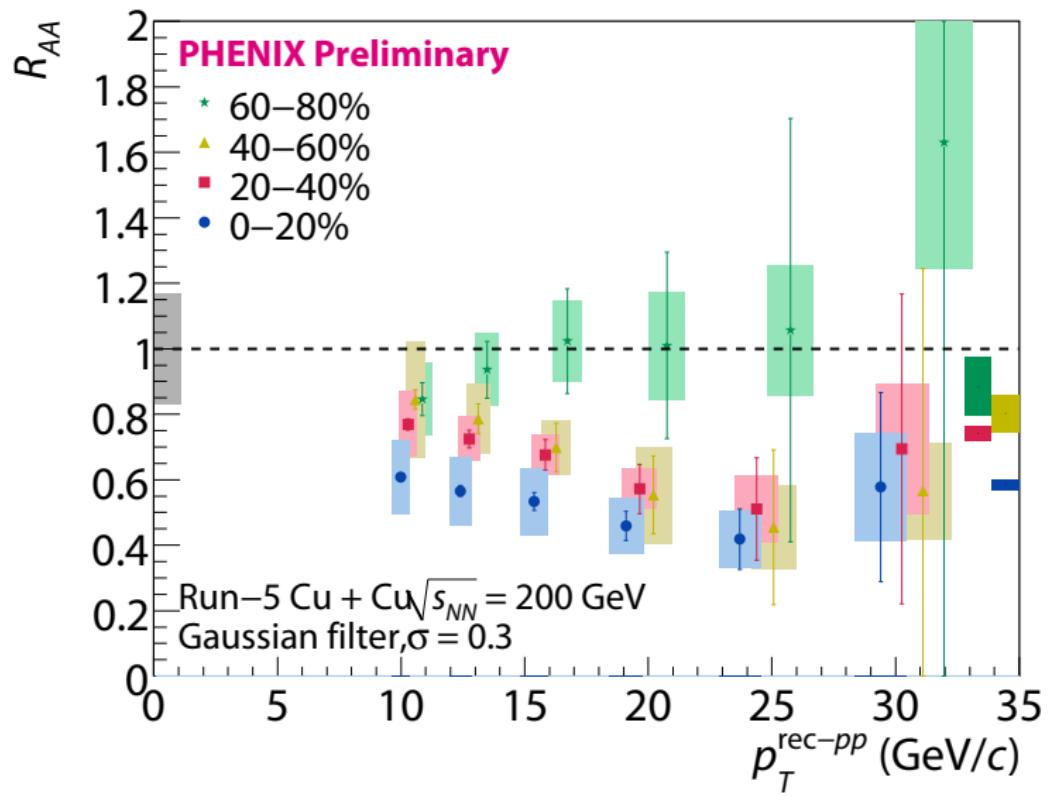


- Pedestal $\approx 0.3 \times 10^{-3}$ translates into $\frac{1}{2\pi} \frac{1}{N_{\text{evt}}} \frac{dN}{p_T dp_T dy} \approx 10^{-5} (\text{GeV}/c)^{-2}$, substantial contamination for 7.5 GeV/c
- $17.8 (\text{GeV}/c)^2$ used as standard fake rejection cut level:
 $\Rightarrow < 10\%$ contamination at 7.5 GeV/c

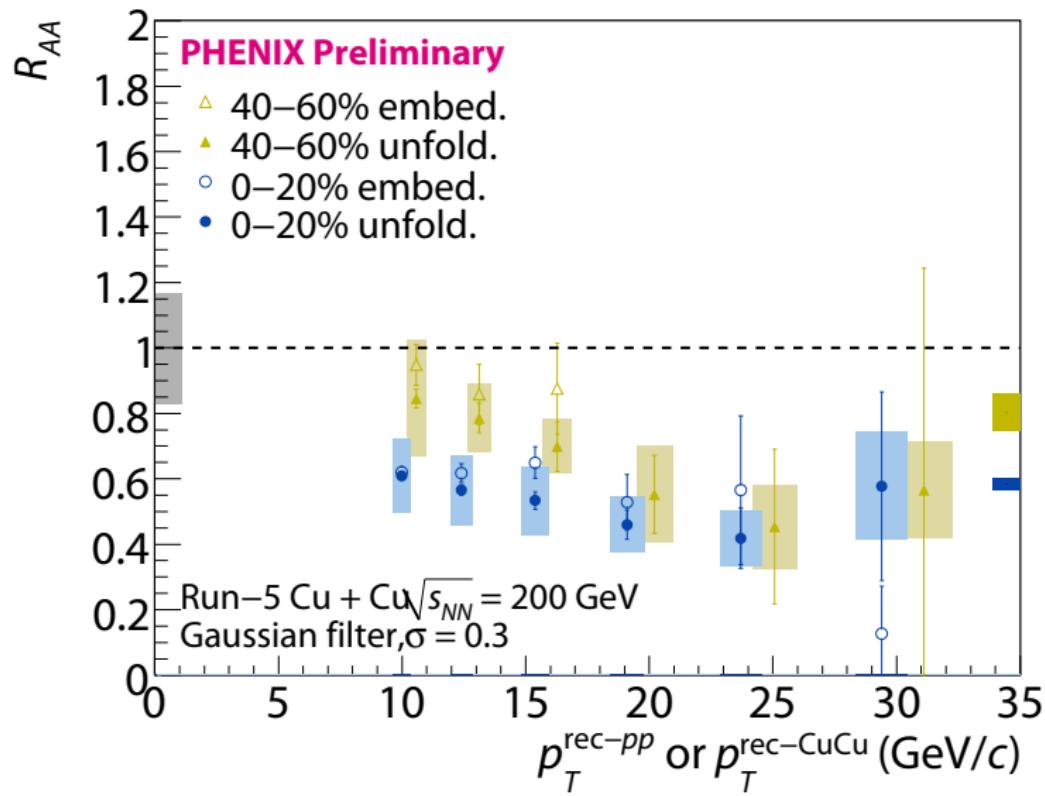
Run-5 Cu + Cu spectra with fake rejection



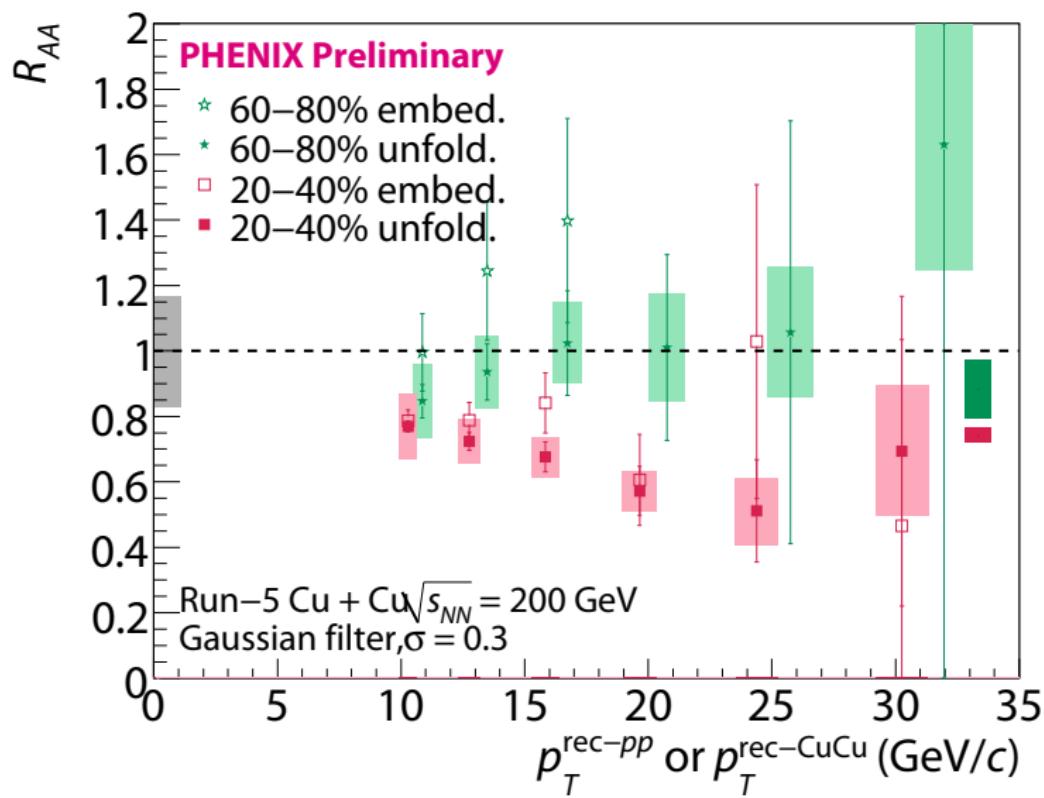
Run-5 Cu + Cu R_{AA}



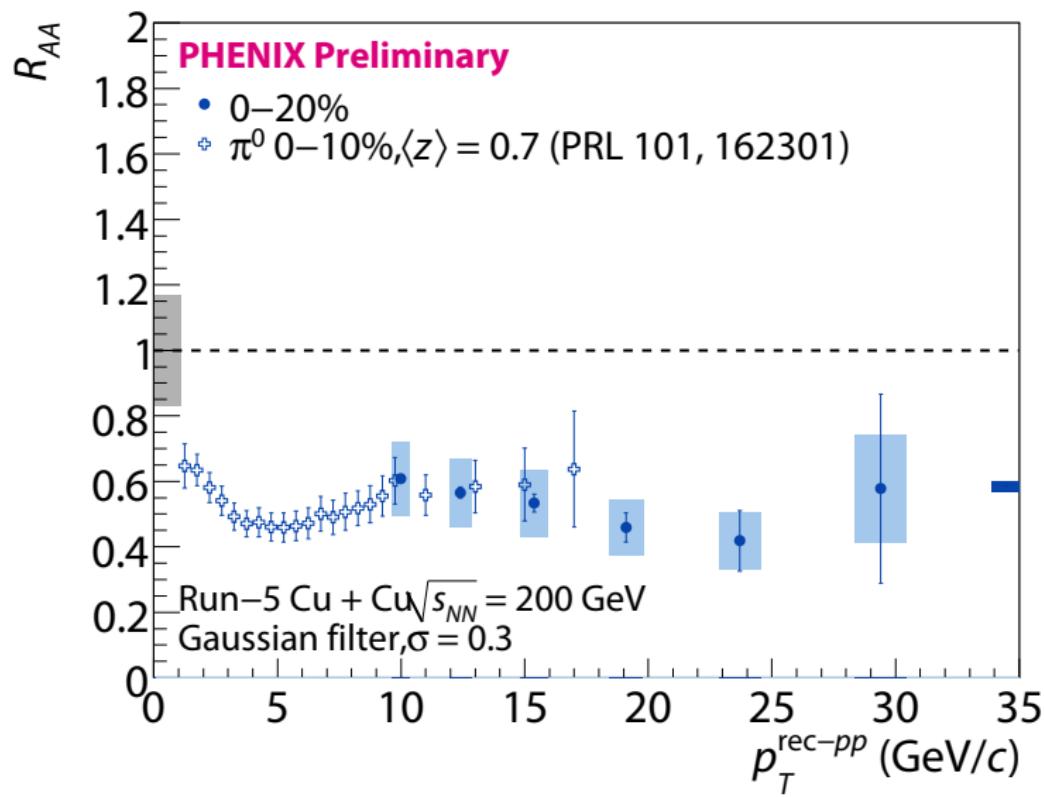
Run-5 Cu + Cu R_{AA} compared to embedding



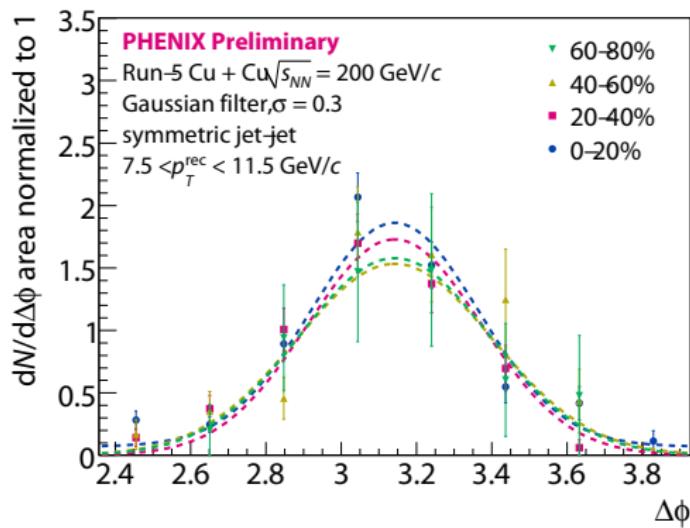
Run-5 Cu + Cu R_{AA} compared to embedding



Run-5 Cu + Cu R_{AA} compared to π^0



Cu + Cu jet-jet azimuthal correlation



- No centrality dependent broadening observed within sensitivity

Centrality	$\Delta\phi \approx \pi$ width σ
0–20%	0.223 ± 0.017
20–40%	0.231 ± 0.016
40–60%	0.260 ± 0.059
60–80%	0.253 ± 0.055

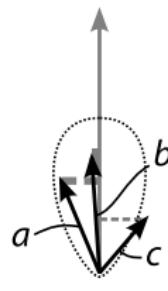
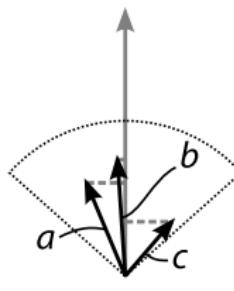
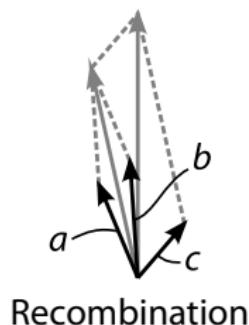
Summary & outlook

- Fake jets must be removed even in Cu + Cu at $\sqrt{s_{NN}} = 200 \text{ GeV}$
- Gaussian filter with the Gaussian fake rejection ($\sigma_{\text{dis}} = 0.1$) a highly effective algorithm for jet reconstruction at RHIC energy
- High-rate, accurate calorimeter makes PHENIX suitable for jet physics
- PHENIX is studying the medium using a uniquely suitable jet reconstruction algorithm with wide p_T range coverage, high efficiency, and low fake rate
- Obtained first measurement of $p + p$ spectrum at RHIC upto 60 GeV/c, across 10 orders of magnitude
- Obtained first measurement of the dijet angular correlation in Cu + Cu collisions
- Obtained first measurement of the jet R_{AA} in Cu + Cu collisions
- Cu + Cu a stepping stone in understanding heavy ion jet reconstruction
 - ⇒ We are intrigued by the current Cu + Cu results, and aim at understanding its physics implication before moving on to Au + Au
 - We are on the verge of other measurements of jet modification
 - ⇒ fragmentation function
 - ⇒ j_T distribution

Part I

Backup

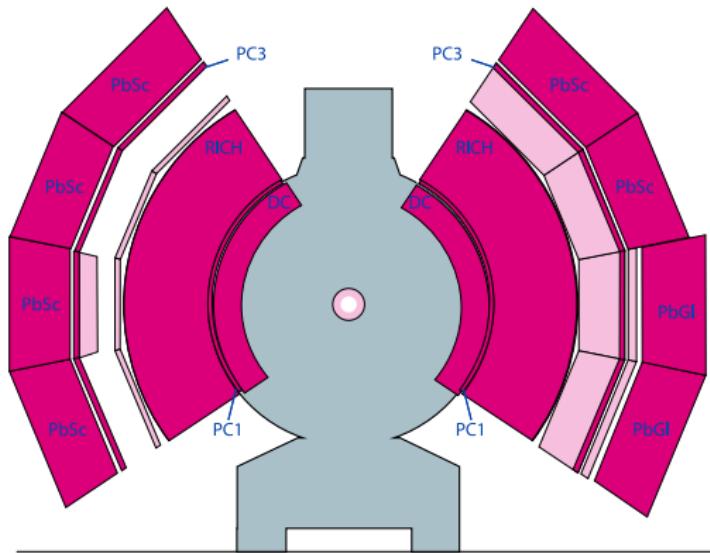
Jet reconstruction algorithms



- k_\perp : Catani, Dokshitzer, Webber, Phys. Lett. B **285**, 291 (1992); Ellis & Soper, Phys. Rev. D **48**, 3160 (1993)
- Cambridge-Aachen, anti- k_\perp

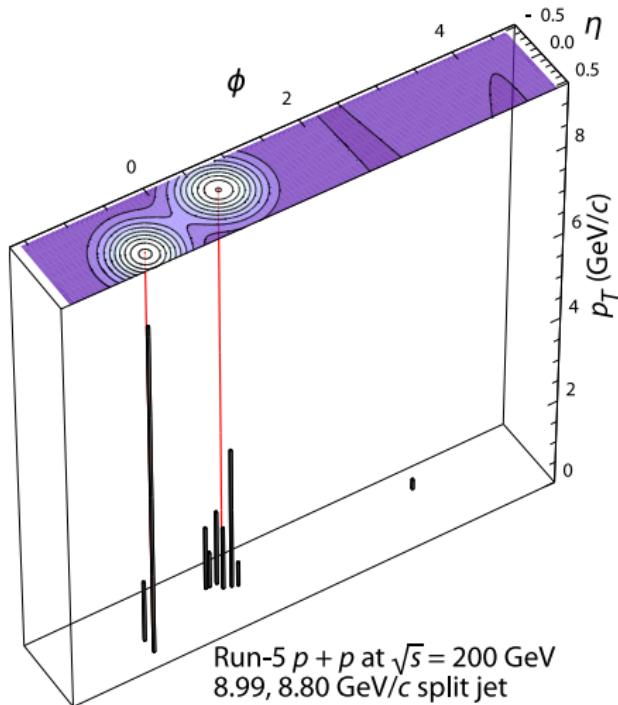
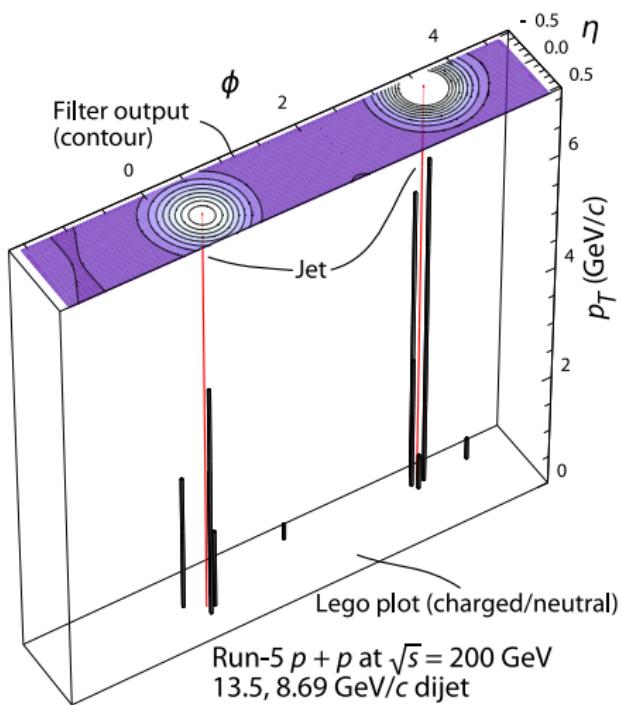
- Angular sampling
 - Cone: Huth *et al.*, 1990 Summer Study on High Energy Physics, 134
 - Filter: **Study for $p + p$ collisions: arXiv:0806.1499**; heavy ion properties & performance: in preparation

Jet reconstruction in PHENIX Run-5

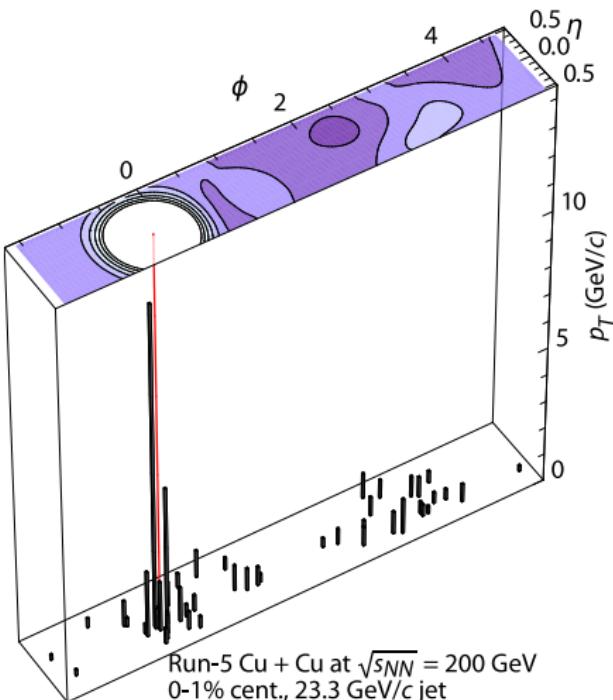
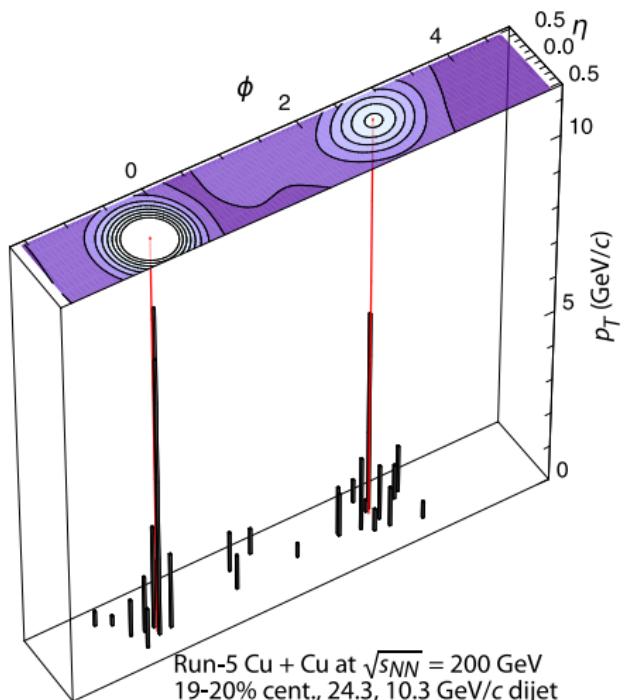


- Data set: PHENIX Run-5 $p + p$ at $\sqrt{s} = 200 \text{ GeV}$, Cu + Cu at $\sqrt{s_{NN}} = 200 \text{ GeV}$
 - Tracking detectors: Drift Chamber (DC), Pad Chambers (PC) 1/3, RICH
 - Calorimeters: Lead-Scintillator (PbSc), Lead-Glass (PbGl)
- Gaussian kernel with $\sigma = 0.3$

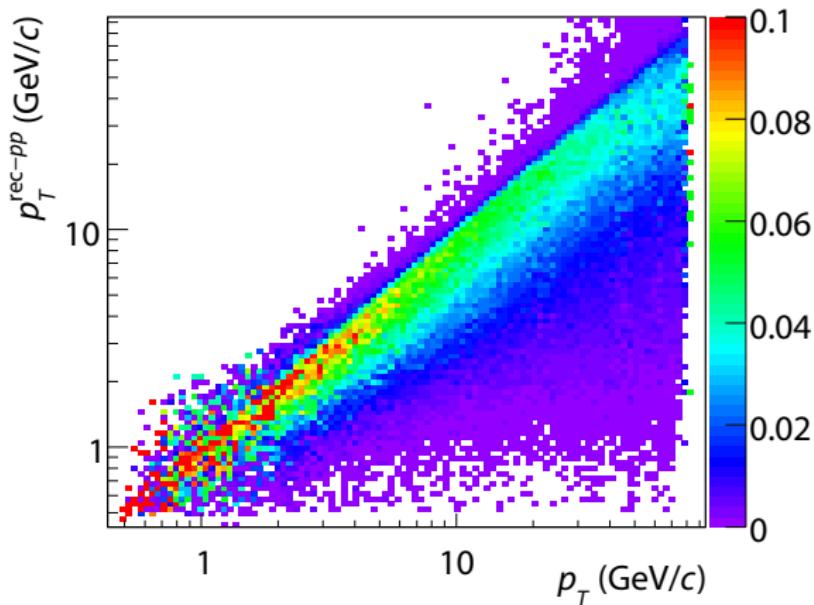
Event display, $p + p$



Event display, Cu + Cu

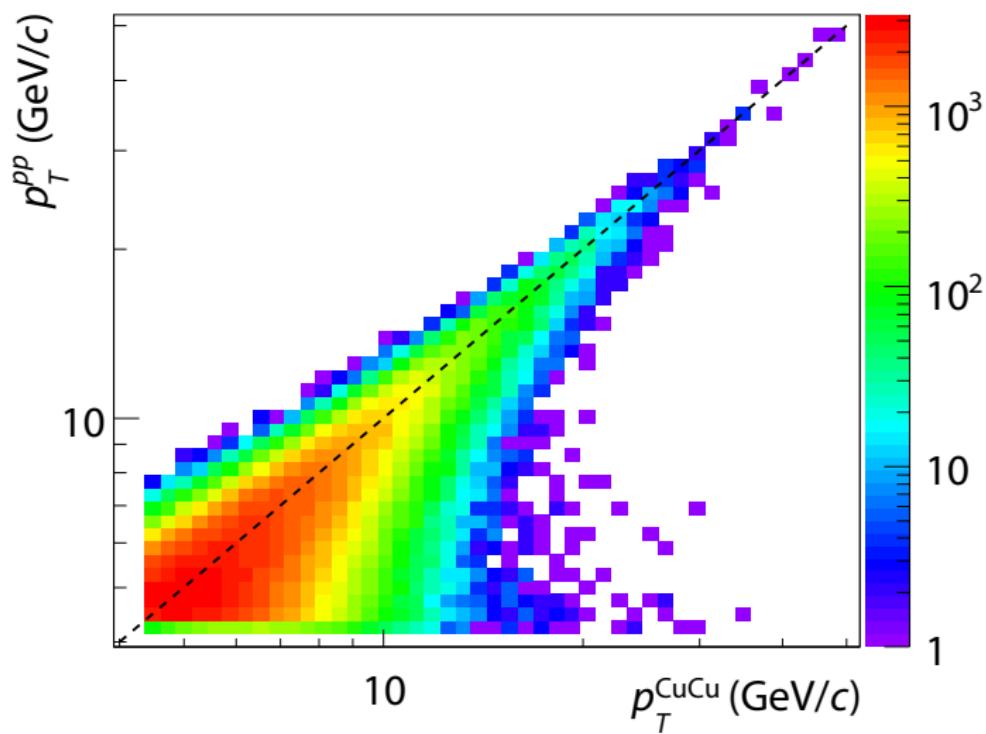


PHENIX jet energy scale

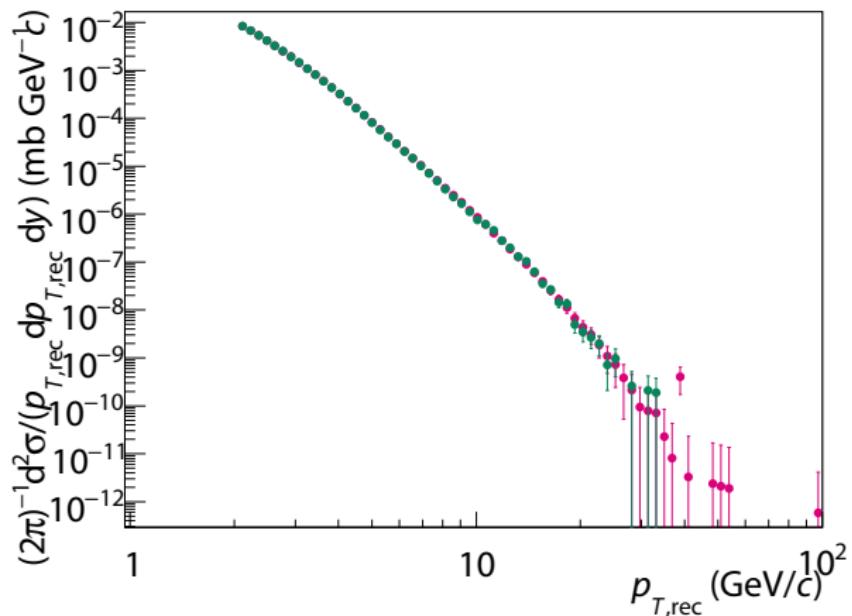


- PYTHIA + GEANT simulation with ~ 16 million events
- $p_T^{\text{rec-}pp} < p_T$ region dominated by n, K_L^0 energy loss

$p + p$ to Cu + Cu transfer matrix, 0–20% centrality

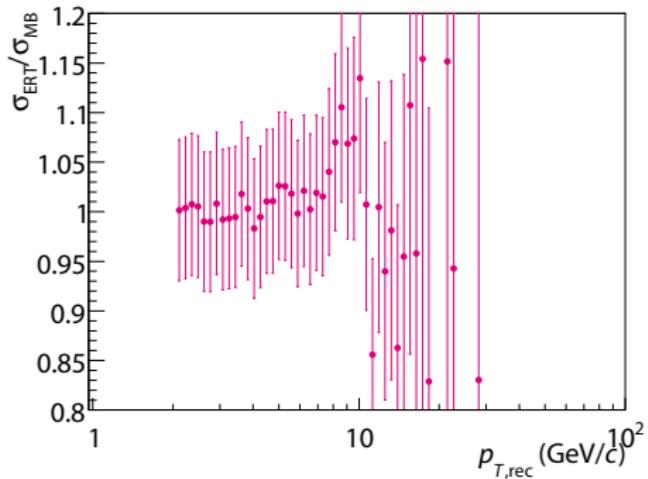
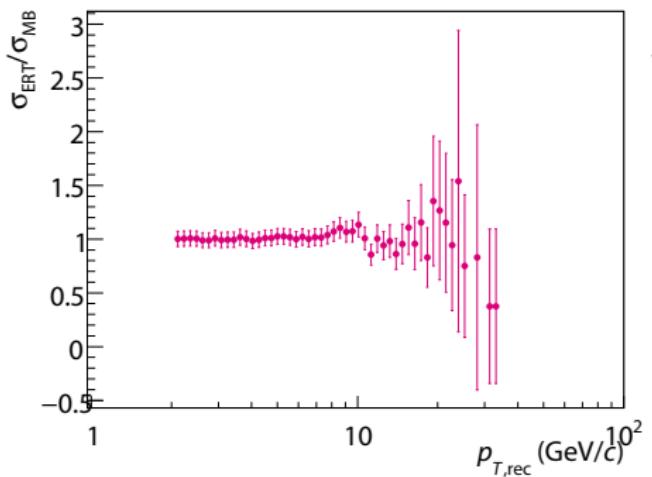


Trigger bias: ERT vs. minimum bias trigger



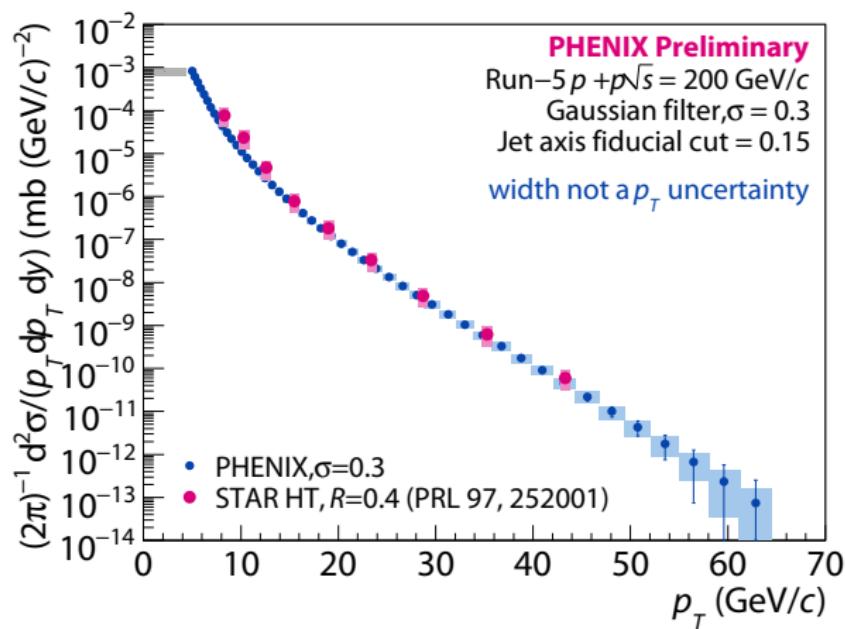
- Triggered data set consistent within 10–15% with minimum bias
- Combined data set used

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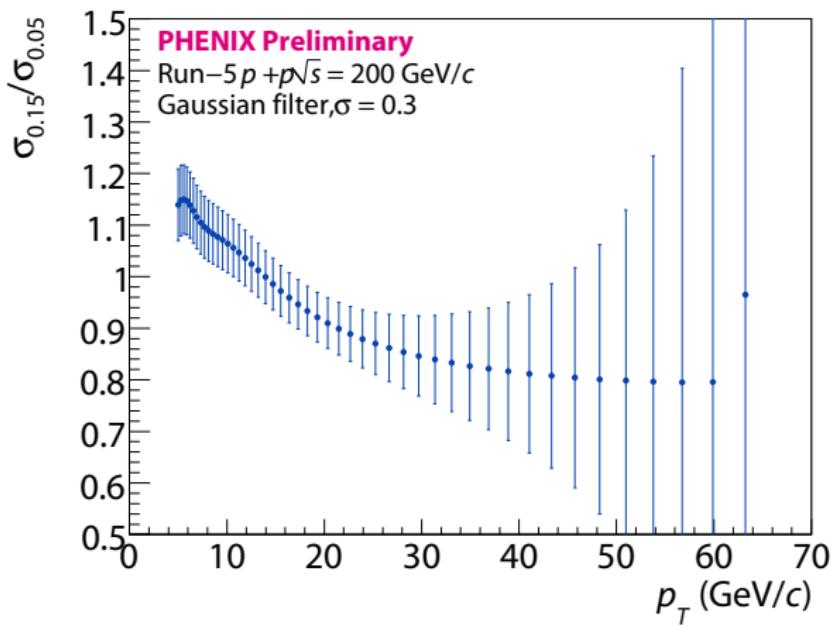
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PHENIX detector edge bias: 0.05 vs 0.15 fiducial cut



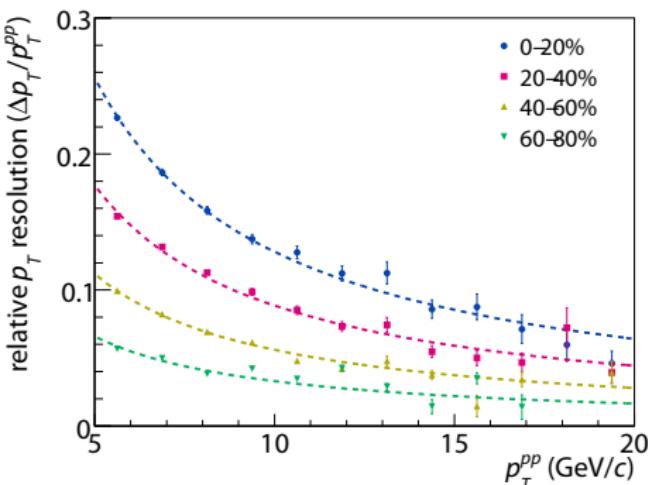
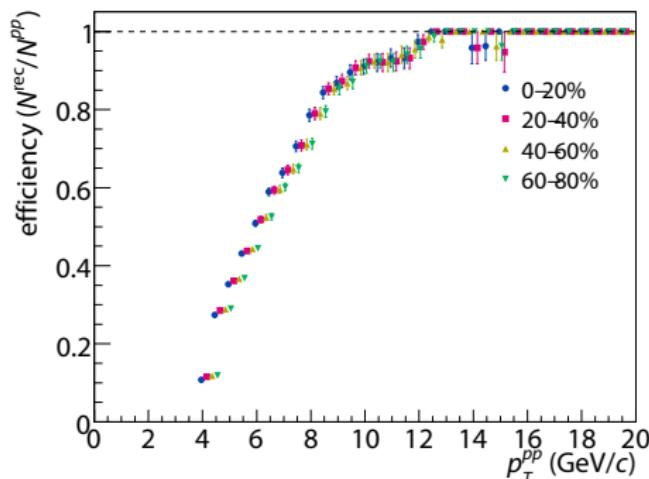
- Cross section remains consistent when lookin only at jets 0.15 in $\Delta\eta$, $\Delta\phi$ from the detector edge
- Residual systematic effect $\approx 15\%$, \ll systematics due to energy scale

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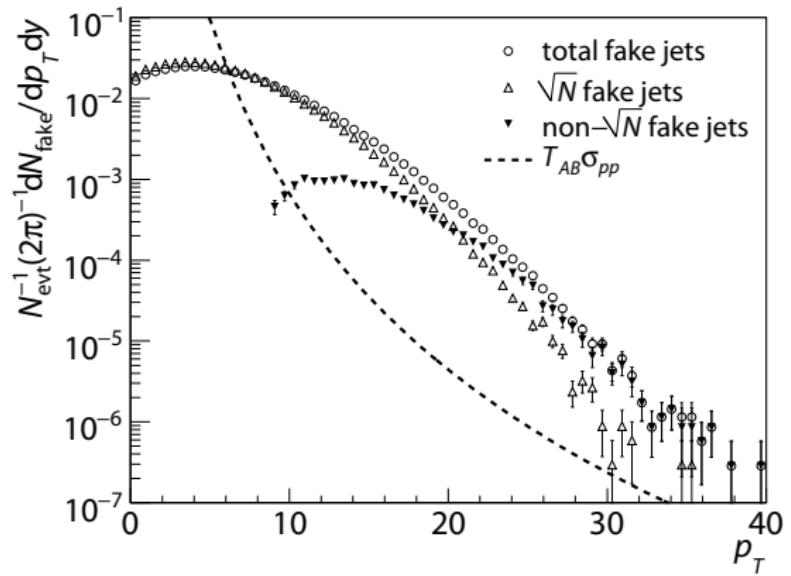
$p + p$ embedding in Cu + Cu: performance



Several desirable properties for heavy ion jet reconstruction:

- Fast saturation to unitary efficiency
- **Negligible centrality dependence of jet reconstruction efficiency**
 - Efficiency includes the fake rejection
- The energy resolution follows $1/p_T$

Approach (3): QCD background: \sqrt{N} ?



- $\sqrt{s_{NN}} = 200 \text{ GeV Au + Au HIJING}$
- Most of the high p_T portion not \sqrt{N} fluctuation, yield well above $T_{AB}\sigma_{pp}$
- HIJING background may be overly pessimistic, but demonstrates:
⇒ **\sqrt{N} a highly dangerous assumption**

Zeroth + first order sum p_T (Run-5 $p + p$ ERT)

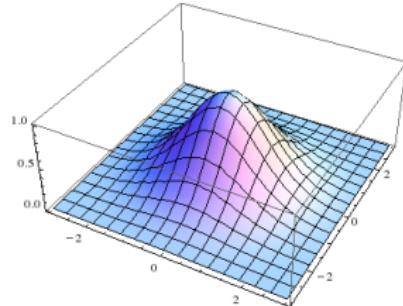
Flat (1D) integration:

$$\begin{aligned}\int dx p_T(x) &= \int dx e^{x^2/(2\sigma)} e^{-x^2/(2\sigma)} p_T(x) \\ &= \underbrace{\int dx e^{x^2/(2\sigma)} p_T(x)}_{p_T^0} + \underbrace{\frac{1}{2\sigma} \int dx x^2 e^{x^2/(2\sigma)} p_T(x)}_{p_T^1} + \dots\end{aligned}$$

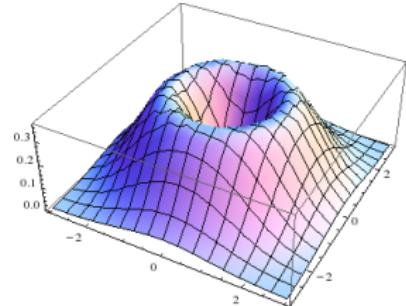
- $p_T^1 \ll p_T^0$ demonstrates that Gaussian filter is not losing significant amount of energy
- p_T^1 is closely related to the jet width, possible interesting physics

Zeroth + first order sum p_T (Run-5 $p + p$ ERT)

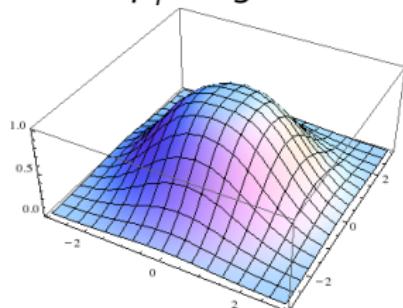
In pictures:



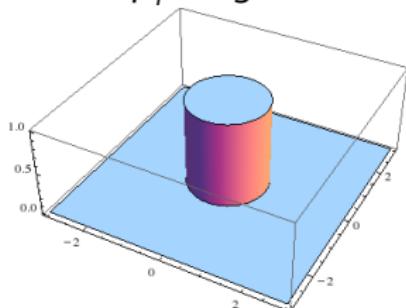
p_T^0 weight



p_T^1 weight



$p_T^0 + p_T^1$ weight



cone

Zeroth + first order sum p_T (Run-5 $p_T + p_T$ ERT)

